Echocardiographic Study of the Anesthetized Cat

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ABSTRACT

Echocardiographic parameters were recorded, measured and statistically analyzed on a population of normal cats under pentobarbital anesthesia.

Results of the study are similar to those obtained by previous investigators. However, this investigation demonstrates the depressant effect of pentobarbital anesthesia on cardiac contractility and the percent change in the left ventricular minor diameter. Analysis by correlation indices shows a positive relationship between the left ventricular diastolic and systolic dimensions, the left ventricular diastolic dimension and the E to F slope of the anterior mitral valve, the left ventricular systolic dimension and the E to F slope, the percent change in left ventricular minor diameter and the velocity of circumferential fibre shortening of the left ventricle and the left atrial dimension and body weight. A negative correlation exists between the left ventricular dimension at systole and the percent change in minor diameter of the left ventricle and the velocity of circumferential fibre shortening .

RÉSUMÉ

Cette expérience consistait à enregistrer, mesurer et effectuer l'analyse statistique des paramètres écho-cardiographiques d'un certain nombre de chats normaux, anesthésiés au pentobarbital. Les résultats s'avérèrent semblables à ceux que d'autres chercheurs avaient déjà obtenus. Elle démontra cependant l'effet dépresseur de cette anesthésie sur la contractilité cardiaque et le pourcentage de changement du plus petit diamètre du ventricule gauche. L'analyse par indices de corrélation révéla une relation positive entre les dimensions diastolique et systolique du ventricule gauche, entre la dimension diastolique du ventricule gauche et la pente E-F de la valvule mitrale antérieure, entre la dimension systolique du ventricule gauche et la pente E-F, ainsi qu'entre le pourcentage de changement du plus petit diamètre du ventricule gauche, la vélocité de contraction des fibres de sa circonférence, la dimension de l'oreillette gauche et le poids corporel. L'expérience permit aussi de constater l'existence d'une corrélation négative entre la dimension du ventricule gauche, au moment de la systole, le pourcentage de changement de son plus petit diamètre et la vélocité de contraction des fibres de sa périphérie.

INTRODUCTION

The use of ultrasound as an investigative tool in human medicine is relatively new. In veterinary medicine its applicability is yet to be determined. Echocardiography is the accepted term for the study of cardiac ultrasound.

Ultrasound is sound above the audible range. Ultrasound got its start in the 1800's when it was first used as a high frequency whistle. With the advent of World War II ultrasound was further developed as a useful military tool for the sonic detection of underwater objects. Not until the 1950's did serious effort take place to apply this tool to the study of the heart. Work by Keidel and Edler in the early 1950's attempted to use ultrasound to study echoes that in retrospect originated from the left ventricular wall (2, 3). Further research and technique refinement led to the use of ultrasound in the diagnosis of cardiac pathology.

Echocardiography utilizes sound waves in the order of frequency of greater than 20,000 cycles per second. A piezoelectric crystal, housed in the form of a transducer, emits ultrasonic waves when subjected to an alternating current at high frequency. The transducer also receives the reflected waves and forwards them to be electronically processed and displayed for interpretation via one of three modes; the A, B or M mode.

Because the velocity of sound transmission through soft tissue is constant, a continuous plot of distance between the transducer and the reflecting surfaces can be plotted per unit time. Patterns of motion appear as images on the M or motion mode.

The benefits of echocardiography are that it is noninvasive, safe and provides quantitative information of wall thickness, internal cardiac dimensions, valve motion, cardiac function and presence or absence of abnormal structures (1, 3, 4, 6). The principal disadvantage of echocardiography is that it propagates poorly through gaseous or bony media.

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MATERIALS AND METHODS

The Electronics for Medicine, Echo IV Echocardiograph/Simultrace Recorder,[1] is a multichannel physiological recording instrument designed to give high resolution recordings of M-mode echocardiograms in concert with other physiological parameters, including an electrocardiogram.

A five megahertz, six millimeter nonfocused transducer was used because of its greater resolution and the shallow depth of beam penetration required.

Cats were judged as having a normal cardiovascular system on the basis of history, physical examination, electrocardiogram and chest radiographs (8, 13, 16). Normal cats were anesthetized with sodium pentobarbital[2] (10, 11, 17, 18).

For echocardiographic study, cats were placed in left lateral recumbency. A three lead electrocardiogram (ECG) cable was attached to the limbs. The cardiac window on the right hemithorax was shaved. Contact paste was applied, and the transducer was positioned in the third or fourth intercostal space near the sternum (Fig. 1). The transducer head was angled dorsocranially and slightly medially and rotated in a small circle until areas of the cardiac shadow could be identified (Fig. 2). The study was deemed complete when satisfactory recordings of the left ventricle, mitral valve, aorta and left atrium were obtained. Methods for measuring the echocardiographic parameters are illustrated in Fig. 3 to 7 (3).

In an attempt to establish echocardiographic parameters for the normal group the parameters were statistically analyzed (Table III) (14). The mean ($\bar{X}$), the variance (S^2) and the standard deviation (S) was calculated for each parameter. Each parameter was then retested to determine repeatability. The value for a specific parameter on the same cat at different times, the $\frac{\text{measure error}}{\text{mean}}$ or

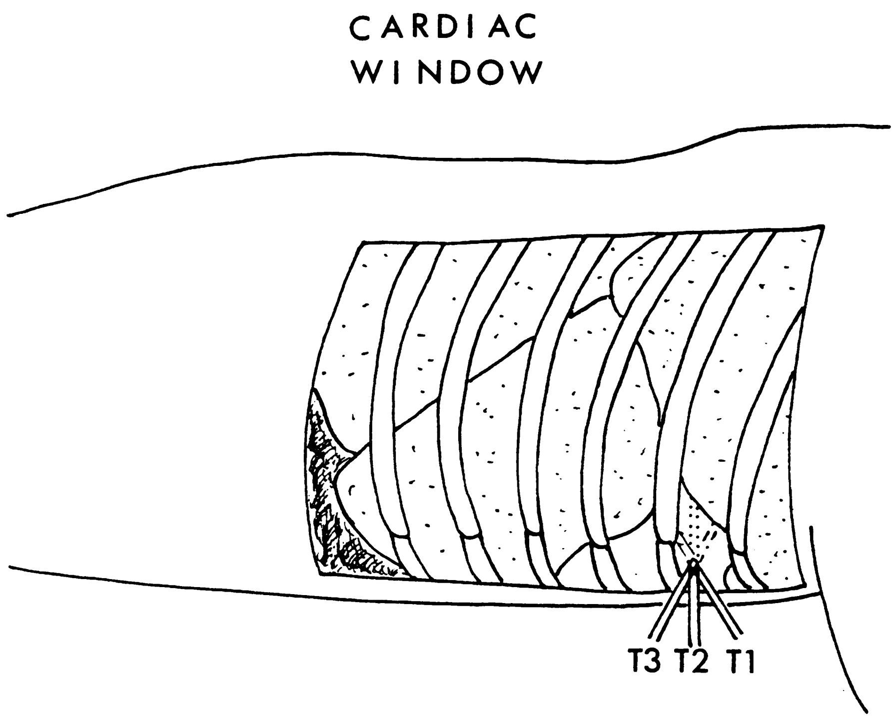

Fig. 1. Movement of the transducer (T) delineates the left ventricle in position T_1, the mitral valve in position T_2 and the aorta; left atrium in position T_3. The lungs (stippled), liver (shaded) and cardiac window (clear) are represented.

TABLE I. Echocardiographic Parameters of Anesthetized Cats

Animal I.D.	Left Ven. Dimen. Dias. cm LVDd	Left Ven. Dimen. Sys. cm LVDs	Percent Change Minor Diam. % %dD	Ejection Time sec E.T.	Velocity of Circum. Short. cm/sec VcF	Left Ven. Post. Wall cm LVPW	Interven. Septum cm IVS	Aorta cm Ao.	Left Atrium cm LA	Heart Rate per min. Ht. Rt.	Body Weight kg. Bdy. Wt.
A	1.32	0.71	46.0	0.22	2.10	0.43	0.40	0.91	0.93	145	3.55
B	1.14	0.76	33.3	0.18	1.81	0.41	0.36	0.83	0.97	165	3.00
C	1.43	0.99	30.8	0.16	1.91	0.32	0.41	0.80	0.95	165	3.00
D	1.52	1.22	19.7	0.17	1.15	0.42	0.41	0.86	1.10	180	5.00
E	1.24	0.70	43.6	0.18	2.46	0.42	0.41	0.91	0.96	145	3.60
G	1.35	0.90	33.3	0.16	2.05	0.41	0.45	0.83	1.10	155	4.60
H	1.17	0.72	38.5	0.14	2.81	0.38	0.38	0.97	1.07	165	3.80
I	1.21	0.78	35.5	0.14	2.53	0.37	0.35	0.90	0.91	180	3.20
J	1.30	0.84	35.4	0.18	2.00	0.44	0.44	0.94	1.02	155	2.90
K	1.27	0.96	24.4	0.15	1.63	0.42	0.42	1.02	1.02	150	3.70
Mean	1.295	0.859	34.05	0.168	2.045	0.402	0.403	0.897	1.003	175	3.635
Std. Dev.	0.12	0.16	2.51	0.02	0.48	0.04	0.03	0.07	0.07	19.93	0.658

[1]Echo IV, Echocardiograph/Simultrace Recorder, Pleasantville, New York.
[2]Somnotol, MTC Pharmaceuticals, Hamilton, Ontario.

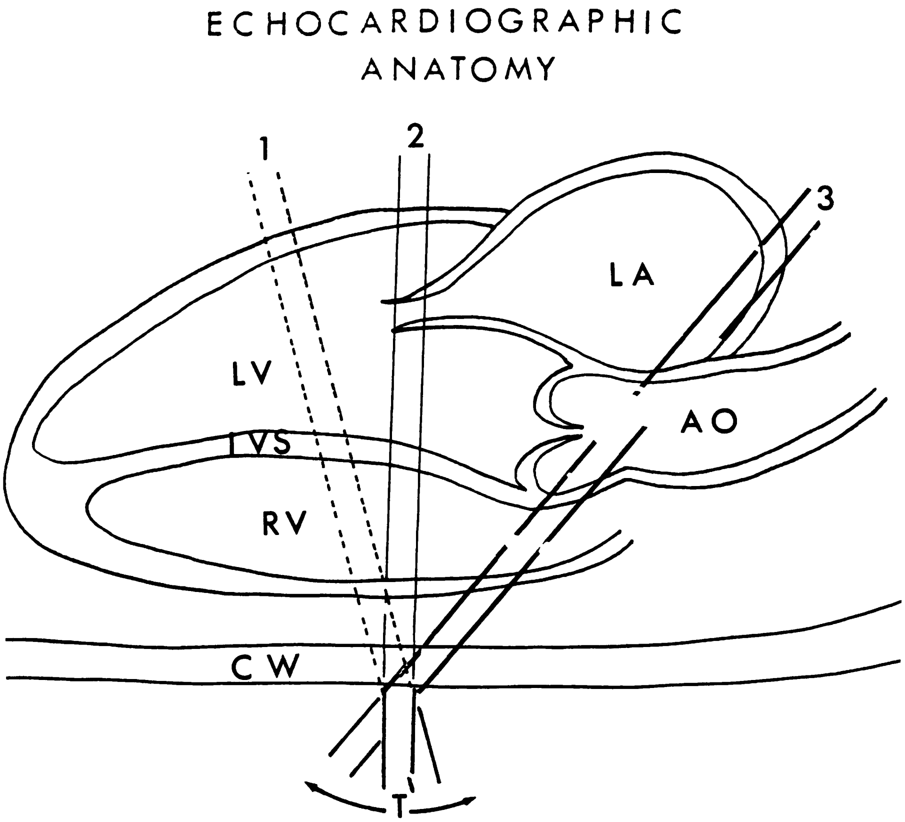

Fig. 2. Movement of the transducer (T) delineates the left ventricle in position 1, the mitral valve in position 2 and the aorta: left atrium in position 3. The right ventricle (RV), interventricular septum (IVS), left ventricle (LV), aorta (Ao), left atrium (LA) and chest wall (CW) are represented.

$\frac{\text{m.e.}}{\bar{X}}$ was calculated. To determine if the value for a given parameter is repeatable for different cats on different occasions the $\frac{\text{variance}}{\text{mean}}$ or $\frac{S^2}{\bar{X}}$ was calculated. Generally the smaller the value is compared to the mean ($\bar{X}$), the greater the repeatability of that value.

Finally, the parameters were correlated to each other (Table IV). In this study positive correlation is one in which the correlated value (r) is greater than or equal to 0.752. As one value increases, so does the value to which it is correlated. Conversely a negatively correlated or inversely related figure ($r = \geqslant -0.752$) would decrease as the value to which it is related increases.

RESULTS

LEFT VENTRICULAR DIASTOLIC DIMENSION

The mean dimension of the left ventricle at end diastole was 1.295 ± 0.12 centimeters (Tables I and III).

The dimensions of the left ventricle during diastole remained constant in the same cat from time to time, $\frac{\text{m.e.}}{\bar{X}} = 0.006$ and between different cats on different occasions, $\frac{S}{\bar{X}} = 0.011$.

The left ventricular diastolic dimension was positively correlated to the left ventricular systolic dimension (r = 0.825) and the EF slope of the anterior mitral value (r = 0.849) (Table IV).

LEFT VENTRICULAR SYSTOLIC DIMENSION

The dimension of the left ventricle in systole was 0.859 ± 0.16 centimeters (Tables I and III).

The dimension of the left ventricle in systole remained constant in the same cat on different occasions, $\frac{\text{m.e.}}{\bar{X}} = 0.006$ and also remained constant between cats on different occasions $\frac{S^2}{\bar{X}} = 0.031$.

The left ventricle dimension at systole was inversely related to the percent change in the minor diameter of the left ventricle (r = -0.903) and the VcF (r = -0.813). It correlated positively with the left ventricular diastolic dimension (r = 0.825) and the EF slope of the anterior mitral valve (r = 0.909) (Table IV).

PERCENT CHANGE OF VENTRICULAR DIMENSION

The percent change in the left ventricular minor diameter was 34.05 ± 2.51 percent (Tables I and III).

The percent change in minor diameter did not appear to be a highly repeatable value in the same cat on different occasions $\frac{\text{m.e.}}{\bar{X}} = 0.10858$ or between cats on different occasions $\frac{S^2}{\bar{X}} = 0.185$.

TABLE II. Mitral Valve Parameters of Anesthetized Cats

Animal I.D.	cm D-E Amp	mm/sec E-F Slope	sec PR-AC	Age
A	0.55	634	0.04	mature
B	0.45	572	0.02	mature
C	0.67	926	0.04	mature
D	0.59	1296	0.03	mature
E	0.52	756	0.05	mature
G	0.45	732	0.03	mature
H	0.52	697	0.04	mature
I	0.48	648	0.03	mature
J	0.50	768	0.03	mature
K	0.54	815	0.04	mature
Mean	0.527	784.4	0.035	
Std. Dev.	0.125	205.62	0.0085	

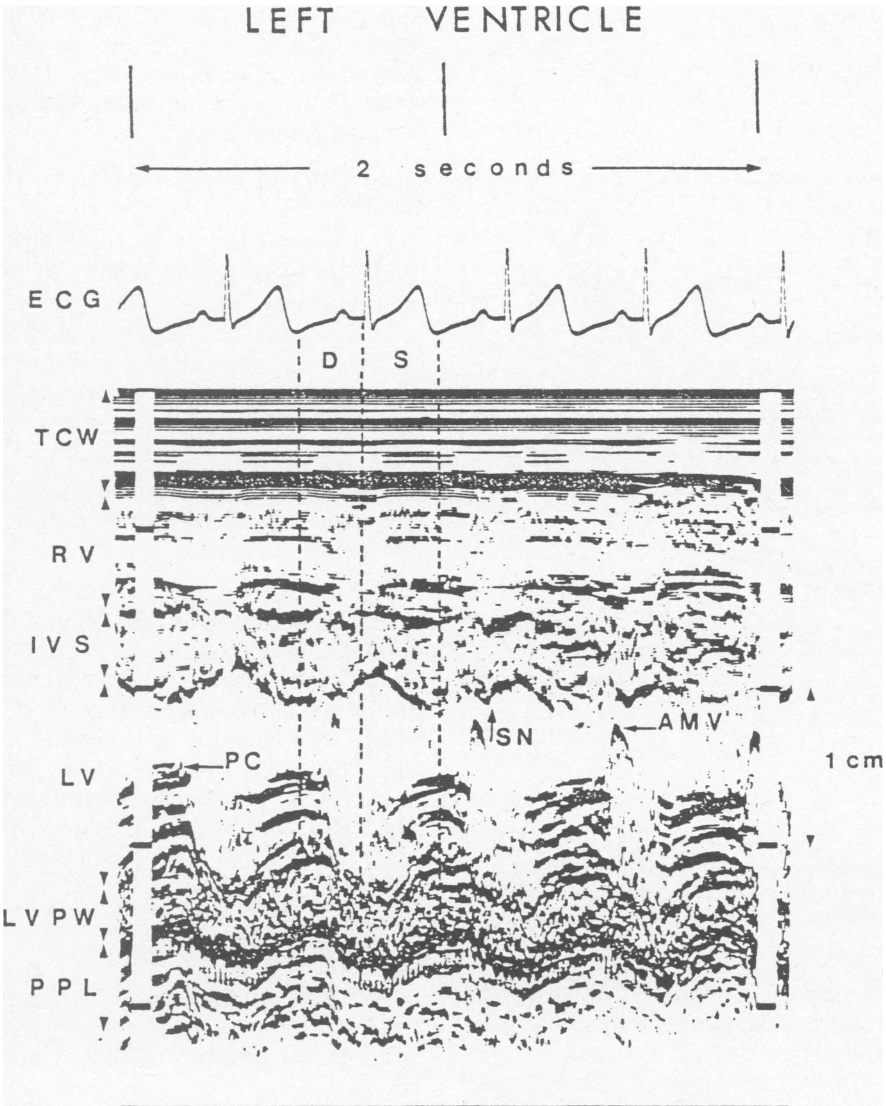

Fig. 3. The area of the left ventricle is shown. The electrocardiogram (ECG), transducer-chest wall image (TCW), right ventricle (RV), interventricular septum (IVS), left ventricle (LV), left ventricular posterior wall (LVPW), pleura-pericardium-lung (PPL), posterior chordae (PC), septal notch (SN) and anterior mitral valve (AMV) are represented. Phases of diastole (D) and systole (S) are labelled. Tissue depth is in centimeters (cm).

TABLE III. Statistical Analysis of Echocardiographic Data of Anesthetized Cats

	$\bar{X}$ Mean	S^2 Variance	S Std. Dev.	$\frac{m.e.}{\bar{X}}$ Repeatability	$\frac{S^2}{\bar{X}}$ Repeatability
LVDd	1.295	0.01367	0.12	0.00567	0.0106
LVDs	0.859	0.02665	0.16	0.00597	0.031
%dD	34.05	6.3163	2.51	0.10858	0.185
E.T.	0.168	0.00057	0.02	0.00491	0.0034
VcF	2.045	0.22716	0.48	0.33166	0.0034
LVPW	0.402	0.00128	0.04	0.000249	0.11108
IVS	0.403	0.00102	0.03	0.000062	0.00319
Ao	0.897	0.004712	0.07	0.000446	0.0034
IA	1.003	0.004845	0.07	0.0148	0.0048
H.R.	175.0	397.2	19.93	9.7143	2.27
D. E. amp.	0.527	0.01563	0.125	0.000076	0.0297
E. F. slope	784.4	42279.58	205.62	29.975	53.90
PR-AC	0.035	0.000072	0.0085	0.0068	0.0021
LA:Ao	1.124	0.01287	0.11345	0.0367	0.0115

The percent change in minor diameter was positively correlated with the velocity of circumferential fibre shortening of the left ventricle (r = 0.766) (Table IV).

LEFT VENTRICULAR POSTERIOR WALL THICKNESS

The mean dimension of the left ventricular posterior wall was 0.402 ± 0.04 centimeters (Tables I and III).

The left ventricular posterior wall dimension remained constant in the same cat from time to time, $\frac{m.e.}{\bar{X}} = 0.0002$ and also remained constant between cats on different occasions, $\frac{S^2}{\bar{X}} = 0.1111$.

The left ventricular posterior wall was not strongly correlated to any other values studied.

EJECTION TIME

The ejection time of the left ventricle was 0.168 ± 0.02 seconds (Tables I and III)

The ejection time is constant in the same cat on different occasions $\frac{m.e.}{\bar{X}} = 0.0049$ and between cats on different occasions $\frac{S^2}{\bar{X}} = 0.0034$.

Ejection time did not strongly correlate with any particular value in this study.

VELOCITY OF CIRCUMFERENTIAL FIBRE SHORTENING

The velocity of circumferential fibre shortening of the left ventricle was 2.045 ± 0.48 centimeters per second (Tables I and III).

The velocity of circumferential fibre shortening was not constant in the same cat from time to time, $\frac{m.e.}{\bar{X}} = 0.3317$. However, it did remain constant between cats on different occasions $\frac{S^2}{\bar{X}} = 0.0034$.

The velocity of circumferential fibre shortening correlated positively with the percent change in minor diameter (r = 0.766) (Table IV).

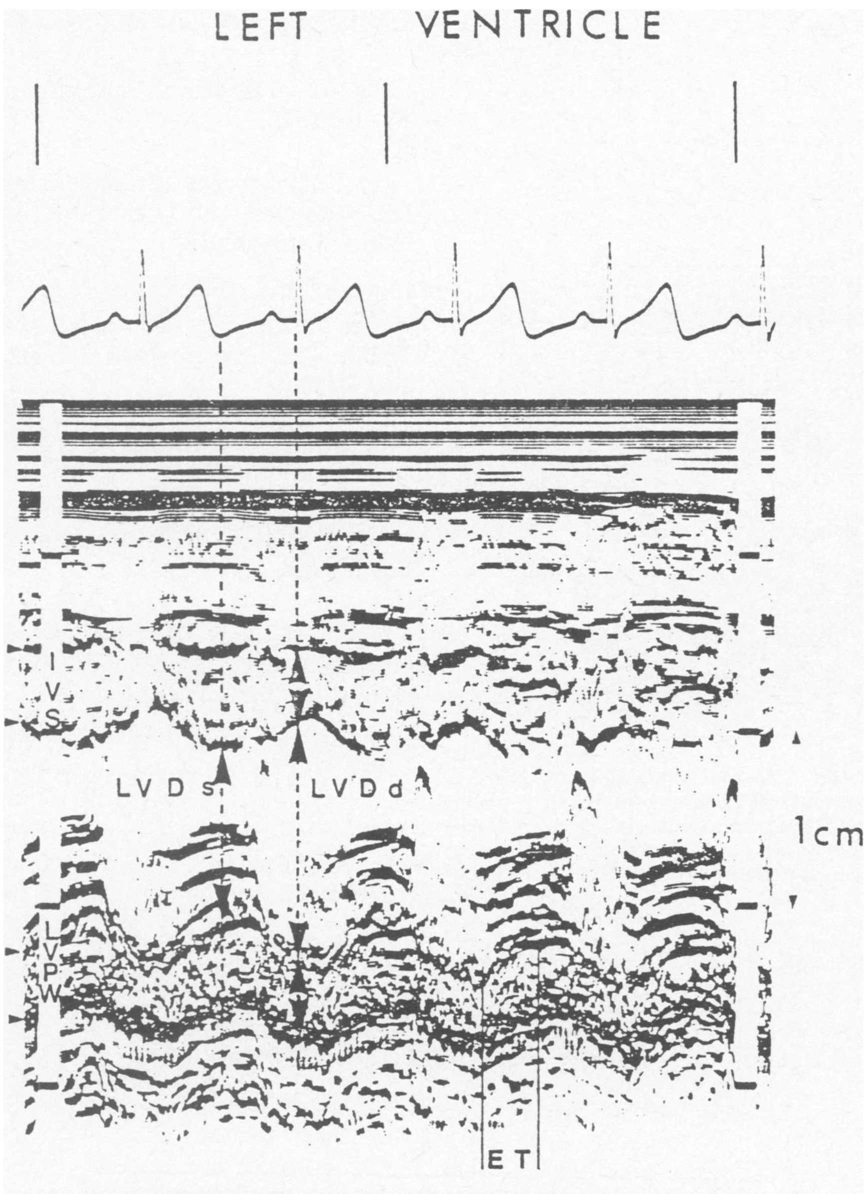

Fig. 4. Measurements of the left ventricular dimension at end diastole (LVDd), left ventricular dimension at systole (LVDs) interventricular septum (IVS), left ventricular posterior wall (LVPW) and ejection time (ET) are represented. Tissue depth is in centimeters (cm).

INTERVENTRICULAR SEPTAL THICKNESS

The dimension of the interventricular septum was 0.403 ± 0.03 centimeters (Tables I and III).

The interventricular septal dimension was constant in the same cat on different occasions $\frac{\text{m.e.}}{\bar{X}} = 0.00006$ and between cats on different occasions $\frac{S^2}{\bar{X}} = 0.0032$.

Septal thickness was not strongly correlated with any other value in this study.

D TO E AMPLITUDE OF THE ANTERIOR MITRAL VALVE

The D to E amplitude of the anterior mitral valve was 0.527 ± 0.125 centimeters (Tables II and III).

The D to E amplitude was constant in the same cat from one time to another $\frac{\text{m.e.}}{\bar{X}} = 0.000076$ and between cats on different occasions $\frac{S^2}{\bar{X}} = 0.0297$.

The D to E amplitude did not correlate with any other value in this study.

E TO F SLOPE OF THE ANTERIOR MITRAL VALVE

The E to F slope of the anterior mitral valve was 784.4 ± 205.62 millimeters per second (Tables II and III).

The E to F slope did not appear to be a highly repeatable value on any occasion, $\frac{\text{m.e.}}{\bar{X}} = 29.975$ and $\frac{S^2}{\bar{X}} = 53.90$.

TABLE IV. Correlation Matrices of Echocardiographic Parameters of Anesthetized Cats

	LVDd	LVDs	%dD	E.T.	VcF	LVPW	IVS	Ao	LA	B.Wt.	H.R.	D.E.	E.F.	PR-AC
LVDd	1.000	0.825	-0.508	0.163	-0.660	-0.077	0.548	-0.379	0.340	0.523	0.118	0.663	0.849	0.061
LVDs		1.000	-0.903	-0.219	-0.813	-0.100	0.364	-0.240	0.519	0.551	0.296	0.511	0.909	0.212
%dD			1.000	0.441	0.766	0.092	-0.170	0.087	-0.508	-0.414	-0.340	-0.274	-0.719	-0.384
E.T.				1.000	-0.232	0.523	0.183	-0.173	-0.283	-0.099	-0.335	0.052	-0.110	0.055
VcF					1.000	-0.256	-0.336	0.245	-0.318	-0.361	-0.104	-0.321	-0.672	0.366
LVPW						1.000	0.343	0.405	0.278	0.266	-0.289	-0.485	-0.046	-0.109
IVS							1.000	0.035	0.524	0.354	-0.325	0.151	0.349	0.225
Ao								1.000	0.074	-0.059	-0.214	-0.143	-0.165	0.390
LA									1.000	0.752	0.079	-0.098	0.492	-0.178
B.Wt.										1.000	0.105	0.019	0.594	0.014
H.R.											1.000	0.064	0.256	-0.344
D.E.												1.000	0.628	0.461
E.F.													1.000	0.057
PR-AC														1.000

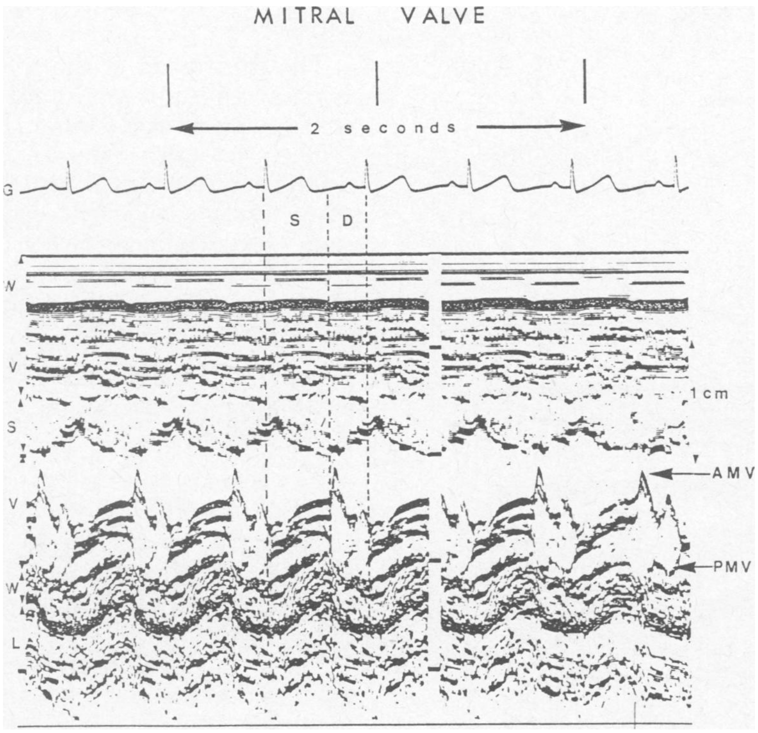

Fig. 5. The area of the mitral valve is shown. The electrocardiogram (ECG), transducer-chest wall image (TCW), right ventricle (RV), interventricular septum (IVS), left ventricle (LV), left ventricular posterior wall (LVPW), pleura-pericardium-lung (PPL), anterior mitral valve (AMV) and posterior mitral valve (PMV) are represented. Phases of systole (S) and diastole (D) are labelled. Tissue depth is in centimeters (cm).

The E to F slope was positively correlated to the left ventricular diastolic dimension (r = 0.849) and the left ventricular systolic dimension (r = 0.909) (Table IV).

P TO R INTERVAL MINUS A TO C INTERVAL

The P to R interval of the electrocardiogram minus the A to C interval of the anterior mitral value was 0.035 ± 0.0085 seconds (Tables II and III).

This value was constant in the same cat from time to time $\frac{\text{m.e.}}{\bar{\bar{X}}} = 0.0068$ and between cats on different occasions $\frac{S^2}{\bar{\bar{X}}} = 0.0021$.

The P to R interval minus A to C interval did not correlate with any other value in this study.

AORTIC ROOT DIMENSION

The aortic root dimension was 0.897 ± 0.07 centimeters (Tables I and III).

The aortic root dimension was constant in the same cat from time to time $\frac{\text{m.e.}}{\bar{\bar{X}}} = 0.0004$ and between cats on different occasions $\frac{S^2}{\bar{\bar{X}}} = 0.0034$.

The aortic root dimension did not correlate well with any other value in this study.

LEFT ATRIAL DIMENSION

The left atrial dimension was 1.003 ± 0.07 centimeters (Tables I and III).

The left atrial dimension was constant in the same cat from one time to another $\frac{\text{m.e.}}{\bar{\bar{X}}} = 0.0148$ and between cats on different occasions $\frac{S^2}{\bar{\bar{X}}} = 0.0048$.

The left atrial dimension was positively correlated to the body weight (r = 0.752) (Table IV).

LEFT ATRIAL:AORTIC ROOT RATIO

The left atrial:aortic root ratio was 1.124 ± 0.114 (Table III).

The left atrial:aortic root ratio was constant in the same cat on different occasions $\frac{\text{m.e.}}{\bar{\bar{X}}} = 0.0367$

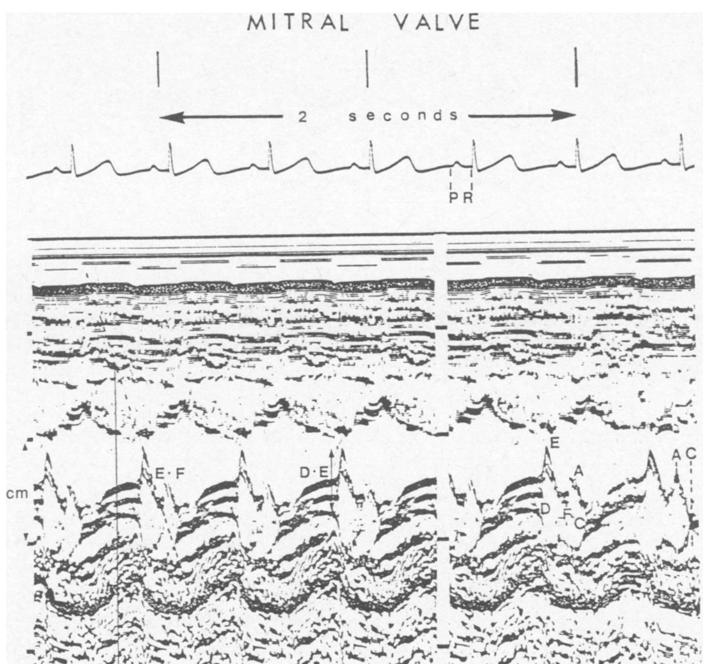

Fig. 6. The anterior mitral valve is labelled D, E, F, A and C according to the text. The E to F slope of the anterior mitral valve, the D to E amplitude of the anterior mitral valve and the A to C interval of the anterior mitral valve are represented. The P to R interval of the electrocardiogram is labelled. Tissue depth is in centimeters (cm).

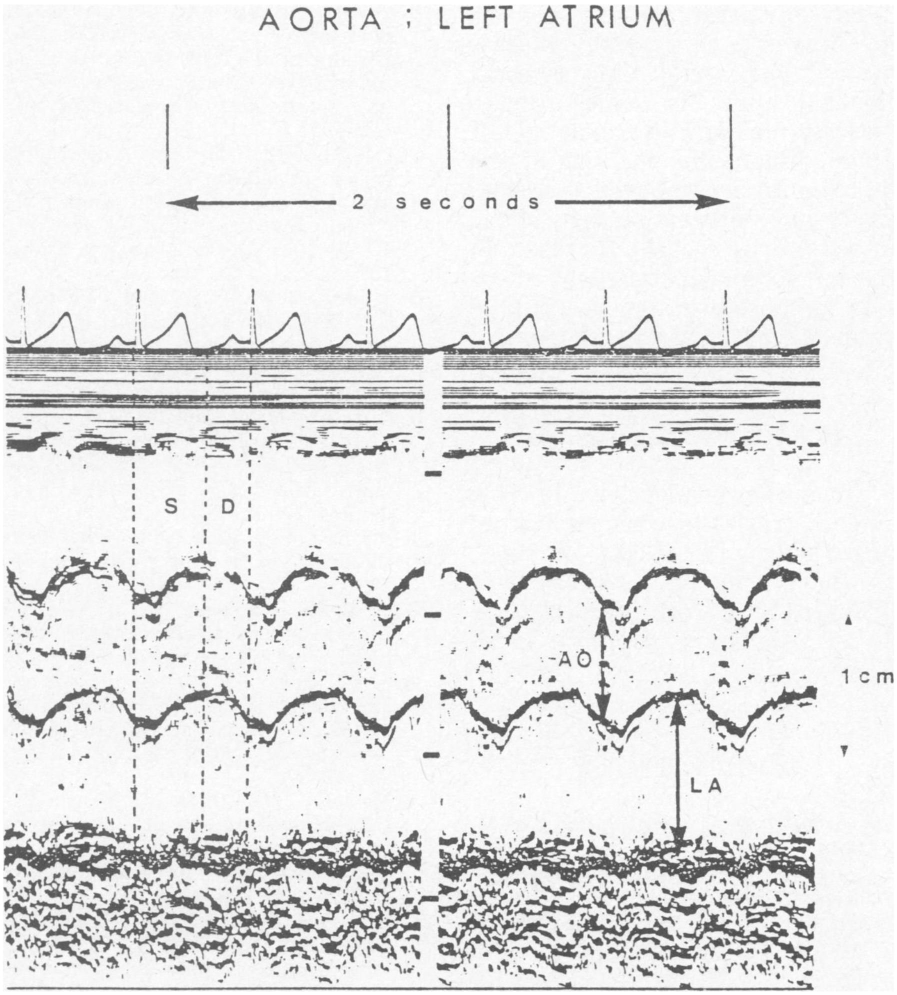

Fig. 7. The area of the aorta and left atrium is shown. The aorta (Ao) and left atrium (LA) are represented. Phases of systole (S) and diastole (D) are labelled. Tissue depth is in centimeters.

and between cats on different occasions $\frac{S^2}{\overline{X}} = 0.0115$.

DISCUSSION

There are only two other published studies to date of feline echocardiography (12, 13).

The values obtained in this study compared to those of Pipers demonstrate a marked similarity in all parameters except percent change in minor diameter (%dD) and velocity of circumferential fibre shortening (VcF). The difference in values might be explained by the effect of the barbiturate anesthetic in this study. Cats in Pipers' study were not anesthetized. Pentobarbital sodium has minor effects on cardiac output, arterial pressure and peripheral resistance. Major or significant depressions of left ventricular function, e.g. percent change in minor diameter and velocity of circumferential fibre shortening have been reported (11, 18). The depressed function is caused by incomplete ventricular emptying rather than a reduction in end diastolic size (18).

The left ventricular dimension at end diastole remained unchanged between anesthetized and unanesthetized cats. However, the percent change in left ventricular minor diameter (%dD) and velocity of circumferential fibre shortening were depressed in those cats under anesthesia. The percent change of minor diameter and velocity of circumferential fibre shortening are indices of cardiac contractility (4, 6).

The left ventricular dimension at diastole was positively correlated to the left ventricular dimension at systole (r = 0.825). When the left ventricular diastolic dimension is large one would expect a corresponding large left ventricular systolic dimension.

The left ventricular dimension at systole is inversely correlated to the velocity of circumferential fibre shortening (r = 0.813). That is, when left ventricular systolic dimensions are large a correspondingly small value for velocity of circumferential fibre shortening is measured.

The Laplace Law states that the myocardial wall tension (T) is equal to the intraventricular pressure (P) multiplied by the ventricular cavity radius (R)/thickness of the chamber wall (W) or:

$$T = P \times \overline{X}\frac{R}{W}$$

According to the force-velocity curve the smaller the myocardial tension the faster the rate of muscle shortening (7). This is due to the rapid sliding of contractile filaments. This rapid sliding leaves less time for individual actin-myosin cross bridging. Since tension is dependent on the number of active cross bridge interactions there is therefore less time for the development of tension in the presence of rapid muscle shortening (9). If the left ventricular dimension at systole is increased (R) and the intraventricular pressure (P) and ventricular wall thickness (W) remain constant, then the myocardial tension (T) will increase and hence, the velocity of circumferential fibre shortening will decrease.

The velocity of circumferential fibre shortening and the percent change in minor diameter are reliable indicators of left ventricular function (6). Lower than normal values indicate depressed or decompensated ventricular function.

The E-F slope is influenced by the amount and rate of blood flow across the mitral valve during early diastole (3). It may also be an indicator of left ventricular compliance. The value for the E-F slope may be decreased in conditions of decreased flow across the mitral valve, e.g. mitral stenosis and in conditions of decreased ventricular compliance, e.g. left ventricular hypertrophy. A positive correlation exists between the E-F slope and the left ventricular diastolic dimension (r = 0.849) and left ventricular systolic dimension (r = 0.909) suggesting that an increased volume of blood in the left ventricle may be related to an increased flow across the mitral valve during diastole.

Brandley and Cornelius (7) also state that heart rate is positively correlated to contractility. As the heart rate increases, contractility increases. This is termed the Bowditch effect and is likely due to altered intracellular electrolyte concentrations. This was not demonstrated in this study (r = -0.104). The absence of heart rate/contractility correlation is not related primarily to the level of consciousness, but to the depression of myocardial contractility induced by general anesthesia (18).

Body weight measurements were positively correlated with left atrial dimension (r = 0.752). With a positive correlation the larger the body weight, the larger the left atrial dimension. Some authors have not been able to demonstrate any correlation while other investigators have shown a positive correlation (3, 6).

Roge *et al* (15) suggests that the use of body weights may be of value when assessing children. Although body weight may change from two to four kilograms, the body surface area remains constant.

The left atrial:aortic root ratio has proven to be a reliable indicator of left atrial enlargement. Because there is some overlap between normal and abnormal left atrial dimensions the size of the left atrium is compared to a relatively indistensible structure, the fibrous aortic root (5). Increases in the left artrial:aortic root dimension is therefore a more reliable value of left atrial enlargement.

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